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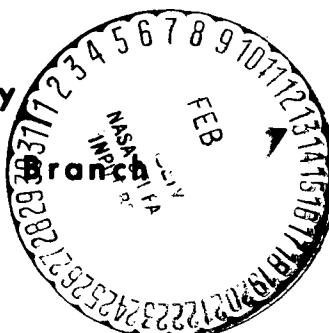
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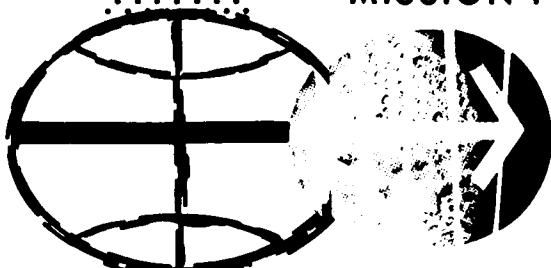
COMPARISON OF THE SENSITIVITY OF LAMBERT AND EXTERNAL ΔV GUIDANCES TO DISPERSIONS IN THE LOI BURNS OF MISSIONS F AND G

By Robert F. Wiley

Lunar Mission Analysis Branch



MISSION PLANNING AND ANALYSIS DIVISION



MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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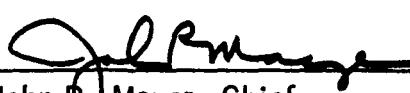
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COMPARISON OF THE SENSITIVITY OF LAMBERT AND EXTERNAL ΔV GUIDANCES
TO DISPERSIONS IN THE LOI BURNS OF MISSIONS F AND G

By Robert F. Wiley

SUMMARY

This study compared the sensitivity of Lambert and external ΔV guidances to dispersions in the lunar orbit insertion (LOI) burns for Missions F and G. Dispersion in (1) thrust, (2) ignition time, (3) state vector, (4) accelerometer bias (5) platform misalignment, and (6) platform drift were simulated individually; then selected combinations of two dispersions were simulated. Two different lunar parking orbits (LPO) were used; a 95- by 80-n. mi. orbit and a 200- by 80-n. mi. orbit. For the Apollo lunar missions presently planned, this study indicates that the dispersion-sensitivity differences between Lambert and external ΔV guidances are negligible.

INTRODUCTION AND ANALYSIS

This study was performed to compare the difference in sensitivity to dispersions of Lambert and external ΔV guidance in Missions F and G LOI burns and thus determine if one particular guidance should be used for this maneuver. Reference 1, an incomplete comparison of this type for the Mission E LOI, indicates that the sensitivity differences are negligible.

Six types of dispersions were considered singly: (1) thrust, (2) ignition time, (3) state vector at ignition time, (4) accelerometer bias (5) platform misalignment, and (6) platform drift. (The data for the accelerometer and platform errors were generated by the Guidance and Performance Branch.) Then state vector dispersions were simulated using two dispersed thrust levels and a dispersed ignition time. In connection with all ignition time dispersions, note that the Lambert time-of-flight guidance parameter was measured as time at the target vector minus ignition time; i.e., the time of flight was updated to account for the dispersed ignition time. This is supposed to happen in the CMC; for instance, if a rough combustion causes a shutdown and the engine is relit in, say 10 seconds, the time of flight used in the first pass through Lambert guidance would be the original time of flight to the target vector minus 10 seconds.

Two target LPO's were used; each was associated with a different approach hyperbola. The nominal parameters of each of these LPO's resulting from Lambert and external ΔV guidances are given in the following table.

Parameter	Guidance	LPO, n. mi.	
		95 by 80	200 by 80
LPO apocynthion altitude, h_a , n. mi.	Lambert	96.96	200.89
	Ext. ΔV	93.47	201.39
LPO pericynthion altitude, h_p , n. mi.	Lambert	78.52	80.92
	Ext. ΔV	79.55	80.88
LPO argument of pericynthion, ω_p , n. mi.	Lambert	-68.64	151.08
	Ext. ΔV	-87.02	148.19
Plane change, deg	Lambert	10.15	1.00
	Ext. ΔV	10.15	1.00
ΔV , fps	Lambert	3263.70	2802.58
	Ext. ΔV	3274.19	2802.21
Guidance constant, c	Lambert	0.70	0.47
	Ext. ΔV	--	--
Transfer angle from node to target vector, deg	Lambert	270.	270.
	Ext. ΔV	--	--

The 20° difference in the 95- by 80-n. mi. LPO orientation resulted from targeting the Lambert burn to the external ΔV burn's resultant LPO. Since varying the guidance constant, c, varies the nodal between the hyperbola and the LPO resulting from the burn, it is possible to burn onto the same shape LPO (defined by apocynthion and pericynthion altitudes) at different orientations. This allows a family of solutions. The above is the first solution encountered of this family.

The dispersions were first computed for the 95- by 80-n. mi. LPO. Because the external ΔV dispersion sensitivities were radically different (as compared to the Lambert dispersion sensitivities) from those noted in reference 1, the 200- by 80-n. mi. target LPO was used to run thrust, ignition time, and state vector dispersions to check the agreement with reference 1.

Reference 2 gives the 3σ uncertainties in the state vector at LOI as 23 000 ft in $|\vec{R}|$ and 10.8 fps in $|\vec{V}|$. These do not include any equation-of-motion biases (such as lunar constants uncertainties) which are noted to have a significant effect. Since out-of-plane measurements were the most uncertain, the given vector magnitude uncertainties were separated into uncertainties in the moon-centered inertial vector components as follows:

$$\Delta X = 1.64579 \text{ n. mi.} \quad \dot{\Delta X} = 5.0 \text{ fps}$$

$$\Delta Y = 1.64579 \text{ n. mi.} \quad \dot{\Delta Y} = 5.0 \text{ fps}$$

$$\Delta Z = 3.29157 \text{ n. mi.} \quad \dot{\Delta Z} = 8.0 \text{ fps}$$

An increase in $|\vec{R}|$ means that the X and Y components of \vec{R} increase in magnitude by 1.64579 n. mi., and the Z component of \vec{R} increases by 3.29157 n. mi. The uncertainties in ΔZ and $\dot{\Delta Z}$ are the largest since they are mostly out of plane. The author was unaware of reference 3 when this study was made, so the above noted uncertainties were used. For comparison, the 3σ dispersions in position and velocity components at LOI from reference 3, are

$$\Delta X = 0.03 \text{ n. mi.} \quad \dot{\Delta X} = 6.45 \text{ n. mi.}$$

$$\Delta Y = 1.62 \text{ n. mi.} \quad \dot{\Delta Y} = 2.49 \text{ n. mi.}$$

$$\Delta Z = 5.52 \text{ n. mi.} \quad \dot{\Delta Z} = 27.70 \text{ n. mi.}$$

These uncertainties are for a different hyperbola and time, but Z is still basically out of plane.

The thrust, ignition time, and hardware dispersions are presented graphically in reference 4. Consequently, the data presented here is in tabular form only.

DISCUSSION OF THE DATA

Tables I and II are self-explanatory. The Lambert burn is less sensitive to dispersions because it can change the amount of LOI ΔV to help lessen the impact of the dispersions.

Tables III(a) and (b) show the results of targeting the burn and burning with a navigation state (i.e., the state used to compute guidance commands) but actually being at another state. The dispersions noted (e.g., increase of actual $|\vec{R}|$ over navigation $|\vec{R}|$) occurred at ignition. From then on, the guidance equations determine the differences between the actual and navigation state. For example, at ignition, both the navigation $|\vec{R}|$ and $|\vec{V}|$ were increased to produce an actual state. The burn was done with Lambert guidance, and the resulting LPO pericynthion altitude was 4.97 n. mi. higher than the nominal.

Table IV is self-explanatory. No external ΔV LPO dispersions occur for the accelerometer Y and Z biases because all thrust is applied along the X axis in the burn simulation used.

Tables V and VI are like table III(b) except that thrust levels different from those for the nominal burn were used. Table VII is also like table III(b) except that the burn was started 12 seconds later than the nominal time, thereby simulating a rough combustion shutdown and restart.

CONCLUSIONS

The major conclusions of this comparative study of Lambert and external ΔV guidances are:

- (1) There is negligible difference between the Lambert and external ΔV guidances with respect to thrust, ignition time, and state vector dispersions for low apocynthion LPO's in the 3σ regions; dispersions larger than 3σ can ~~become~~ non-negligible.
- (2) For combined thrust and state vector dispersions, and ignition time and state vector dispersions for low apocynthion LPO's, Lambert guidance gives more consistent numbers. That is, the external ΔV results vary more from dispersion to dispersion than the Lambert results. Sometimes the external ΔV results are much better, sometimes much worse.

(3) Even though Lambert and external ΔV guidance show negligible differences in sensitivity to individual 3σ dispersions, Lambert guidance would be preferable if low apocynthion LPO's are desired. This is to guard against failure cases and combined dispersions for which the external ΔV guidance is sometimes significantly more sensitive.

TABLE I.- DIFFERENCES BETWEEN THE NOMINAL LPO AND THE
LPO'S RESULTING FROM DISPERSED THRUST LEVELS

(a) 95- by 80-n. mi. nominal LPO

Parameter (a)	Guidance	Thrust level			
		1000 lb high	1000 lb low	2000 lb low	4000 lb low
Δh_p , n. mi.	Lambert	+0.25	-0.25	-0.48	-0.81
	Ext ΔV	+3.90	-4.50	-9.35	-19.97
Δh_a , n. mi.	Lambert	-1.02	+1.13	+2.39	+5.33
	Ext ΔV	-4.56	+5.59	+12.09	+28.52
$\Delta \omega_p$, deg	Lambert	-2.18	+1.58	+2.54	+2.30
	Ext ΔV	+24.23	-5.94	-8.24	-9.51
$\Delta(\Delta V)$, fps	Lambert	+1.81	-0.92	-0.59	+5.88
	Ext. ΔV	0.00	0.00	0.00	-0.07
Wedge angle, deg	Lambert	0.130	0.145	0.306	0.693
	Ext ΔV	0.133	0.146	0.310	0.694

^a $\Delta()$ ≡ actual - nominal; h_p ≡ LPO pericynthion altitude; h_a ≡ LPO apocynthion altitude; ω_p ≡ LPO argument of perigee; ΔV ≡ change in velocity of LOI maneuver; wedge angle ≡ wedge angle between nominal and actual LPO's.

TABLE I.- DIFFERENCES BETWEEN THE NOMINAL LPO AND THE LPO'S

RESULTING FROM DISPERSED THRUST LEVELS - Concluded

(b) 200- by 80-n. mi. nominal LPO

Parameter (a)	Guidance	Thrust level			
		1000 lb high	1000 lb low	2000 lb low	4000 lb low
Δh_p , n. mi.	Lambert	+0.03	+0.04	+0.16	+0.82
	Ext ΔV	+0.08	-0.39	-1.16	-4.20
Δh_a , n. mi.	Lambert	+0.71	-0.74	+1.51	+3.13
	Ext ΔV	+0.72	+1.34	+3.50	+11.28
$\Delta \omega_p$, deg	Lambert	+0.26	-0.31	-0.67	-1.62
	Ext ΔV	+3.86	-4.17	-8.59	-17.88
$\Delta(\Delta V)$, fps	Lambert	+0.14	+0.61	+2.23	+10.09
	Ext ΔV	+0.02	+0.00	0.00	+0.02

^aSee table I(a) for definition of symbols.

TABLE II.- DIFFERENCES BETWEEN THE NOMINAL LPO AND THE
LPO'S RESULTING FROM DISPERSED IGNITION TIMES

(a) 95- by 80-n. mi. nominal LPO

Parameter (a)	Guidance	Ignition time				
		60 sec early	12 sec early	12 sec late	60 sec late	120 sec late
Δh_p , n. mi.	Lambert	+1.15	+0.23	-0.17	-0.23	+0.66
	Ext ΔV	-11.70	+4.59	-5.44	-25.90	-47.54
Δh_a , n. mi.	Lambert	-5.63	-1.22	+1.21	+5.96	+12.28
	Ext ΔV	+17.45	-4.22	+5.45	+29.90	+65.08
$\Delta \omega_p$, deg	Lambert	-25.40	-1.61	-0.61	-3.52	-18.30
	Ext ΔV	+150.09	+46.24	-8.88	-14.92	-14.86
$\Delta(\Delta V)$, fps	Lambert	+29.83	+3.31	-1.95	+3.64	+40.91
	Ext ΔV	0.00	0.00	0.00	0.00	0.00
Wedge angle, deg	Lambert	0.817	0.165	0.165	0.816	1.659
	Ext ΔV	0.811	0.163	0.163	0.811	1.619

^aSee table I(a) for definition of symbols.

TABLE II.- DIFFERENCES BETWEEN THE NOMINAL LPO AND THE
LPO'S RESULTING FROM DISPERSED IGNITION TIMES - Concluded

(b) 200- by 80-n. mi. nominal LPO

Parameter (a)	Guidance	Ignition time				
		60 sec early	12 sec early	12 sec late	60 sec late	120 sec late
Δh_p , n. mi.	Lambert	+1.61	+0.08	+0.04	+1.43	+5.87
	Ext ΔV	-4.49	+0.05	-0.56	-7.21	-21.28
Δh_a , n. mi.	Lambert	-5.85	-1.01	+0.94	+3.96	+6.26
	Ext ΔV	+9.89	+0.27	+0.63	+11.43	+39.27
$\Delta \omega_p$, deg	Lambert	+1.59	+0.36	-0.39	-2.24	-5.49
	Ext ΔV	+25.01	+5.41	-5.36	-24.02	-38.37
$\Delta(\Delta V)$, fps	Lambert	+20.57	+1.71	-0.49	+9.90	+50.53
	Ext ΔV	0.00	0.00	0.00	0.00	0.00

^aSee table I(a) for definition of symbols.

TABLE III.- DIFFERENCE BETWEEN THE NOMINAL AND ACTUAL LPO'S DUE
TO DIFFERENCES BETWEEN THE NAVIGATION AND ACTUAL STATE VECTORS AT IGNITION

(a) 95- by 80-n. mi. nominal LPO

Parameter (a)	Guidance	Dispersions in actual navigation				$ R $, $ V $	$ R $, $ V $	$ R $, $ V $
		Increase increase	$ R $, $ V $	Decrease decrease	$ R $, $ V $			
Δh_p , n. mi.	Lambert	+4.97		-6.10		+4.97		-6.14
	Ext. ΔV	+5.86		-7.00		+5.95		-6.91
Δh_a , n. mi.	Lambert	+5.07		-4.04		+2.92		-1.84
	Ext. ΔV	+4.17		-3.11		+1.96		-1.07
$\Delta \omega_p$, deg	Lambert	+19.88		-17.95		+22.77		-16.14
	Ext. ΔV	+25.72		-17.61		+27.60		-13.81
Wedge angle be- tween nom- inal and actual, deg	Lambert	0.108				0.147		0.147
	Ext. ΔV	0.107		0.108		0.147		0.147

^aSee table I(a) for definition of symbols.

TABLE III.- DIFFERENCE BETWEEN THE NOMINAL AND ACTUAL LPO'S DUE
TO DIFFERENCES BETWEEN THE NAVIGATION AND ACTUAL STATE VECTORS AT IGNITION - Concluded

(b) 200- by 80-n. mi. nominal LPO

Parameter (a)	Guidance	Dispersions in actual navigation				$ R $, $ V $ from	
		Increase increase	$ R $, $ V $	Decrease decrease	$ R $, $ V $		
Δh_p , n. mi.	Lambert	+3.12		-3.19		+3.05	-3.20
	Ext ΔV	+3.19		-3.30		+3.18	-3.37
Δh_a , n. mi.	Lambert	+9.96		-9.92		+9.27	-9.13
	Ext ΔV	+9.83		-9.87		+9.09	-9.03
$\Delta \omega_p$, deg	Lambert	+1.47		-1.68		+2.35	-2.63
	Ext ΔV	+1.48		-1.93		+2.34	-2.85

a. See table I(a) for definition of symbols.

TABLE IV.-- DIFFERENCES BETWEEN THE NOMINAL 95- BY 80-N. MI.
 LPO AND THE LPO'S RESULTING FROM ACCELEROMETER
 BIASES AND PLATFORM MISALIGNMENT AND DRIFT

Dispersion source	Δh_a , n. mi.		Δh_p , n. mi.	
	Lambert	Ext ΔV	Lambert	Ext ΔV
Accelerometer X-bias:				
20 σ	+32.63	+30.37	+2.46	+5.18
3 σ	+4.73	+3.40	+0.83	+1.71
Accelerometer Y-bias:				
20 σ	+17.29	0.00	+1.53	0.00
3 σ	+2.39	0.00	+0.39	0.00
Accelerometer Z-bias:				
20 σ	+7.14	0.00	-9.89	0.00
3 σ	+0.89	0.00	-1.32	0.00
Platform Y-misalign:				
20 σ	+8.47	+9.41	-9.14	-10.22
3 σ	+1.09	+1.37	-1.25	-1.54
Platform Z-misalign:				
20 σ	-10.83	-7.66	-6.53	-9.95
3 σ	-2.81	-1.74	-0.47	-0.95
Platform X-drift:				
20 σ	-1.34	+1.10	-0.08	+0.72
3 σ	-0.20	+1.10	-0.01	+0.72
Platform Y-drift:				
20 σ	+12.00	14.16	-12.73	-12.80
3 σ	+1.53	+2.92	-1.75	-1.28
Platform Z-drift:				
20 σ	-12.40	-8.48	-11.08	-12.65
3 σ	-2.97	-1.36	-0.69	-0.41

TABLE V.- DIFFERENCES BETWEEN THE NOMINAL 95- BY 80-N. MI. LPO AND THE ACTUAL LPO'S DUE TO DIFFERENCES BETWEEN THE NAVIGATED AND ACTUAL STATE VECTORS
AT IGNITION WITH A 1000-LB LOW THRUST

Parameter (a)	Guidance	Dispersions in actual		$ R $, $ V $	and $ V $	from navigation	$ R $, $ V $	Decrease $ R $, increase $ V $,	$ V $
		Increase increase	$ R $, $ V $						
Δh_p , n. mi.	Lambert	+4.75		-6.31		+4.72		-6.31	
	Ext. ΔV	+1.85		-11.76		+1.89		-11.61	
Δh_a , n. mi.	Lambert	+6.20		-2.97		+3.87		-0.61	
	Ext. ΔV	+9.24		-2.69		+6.87		-4.88	
$\Delta \omega_p$, deg	Lambert	+20.13		-15.46		+22.69		-13.69	
	Ext. ΔV	+7.66		-16.54		+6.26		-13.82	

^aSee table I(a) for definition of symbols.

TABLE VI.- DIFFERENCES BETWEEN THE NOMINAL 95- BY 80-N. MI. LPO AND THE ACTUAL LPO'S DUE TO DIFFERENCES BETWEEN THE NAVIGATED AND ACTUAL STATE VECTORS
AT IGNITION WITH A 1500-LB HIGH THRUST

Parameter (a)	Guidance	Dispersions in actual				V and from navigation	R and V
		Increase increase	R , V	Decrease decrease	R , V		
Δh_p , n. mi.	Lambert	+5.40	-5.83		+5.44		-5.92
	Ext. ΔV	+7.90	-0.74		+6.14		-0.69
Δh_a , n. mi.	Lambert	+3.53	-5.37		+1.60		-3.39
	Ext. ΔV	+2.05	-10.26		+1.14		-8.43
$\Delta \omega_p$, deg	Lambert	+18.52	-22.76		+21.78		-20.77
	Ext. ΔV	+98.26	-26.88		+111.36		-14.50

a. See table I(a) for definition of symbols.

TABLE VII.- DIFFERENCES BETWEEN THE NOMINAL 95- BY 80-N. MI. LPO AND THE ACTUAL LPO'S DUE TO DIFFERENCES BETWEEN THE NAVIGATED AND ACTUAL STATE VECTORS
AT IGNITION WITH A 12-SECOND IGNITION TIME DELAY

Parameter (a)	Guidance	Dispersions in actual			R and V from navigation	R and V
		Increase increase	R , V	Decrease decrease		
Δh_p , n. mi.	Lambert	+4.85		-6.24	+4.84	-6.25
	Ext ΔV	+1.04		-12.76	+1.55	-12.61
Δh_a , n. mi.	Lambert	+6.24		-2.86	+3.98	-0.56
	Ext ΔV	+8.95		+2.65	+6.66	+4.76
$\Delta \omega_p$, deg fps	Lambert	+19.16		-16.31	+21.66	-14.58
	Ext ΔV	+3.94		-18.74	+2.28	-16.08
$\Delta(\Delta V)$ fps	Lambert	-1.99		-1.99	-1.99	-1.99
	Ext ΔV	0.00		0.00	0.00	0.00

^aSee table I(a) for definition of symbols.

REFERENCES

1. Wiley, Robert F.: Sensitivity of Lambert and External ΔV Guided Burns to Thrust and Ignition Time Dispersions in AS-503 (Lunar Landing Rehearsal) LOI. MSC Memorandum 67-FM54-374, October 16, 1967.
2. Cooley, J. L.: The Effects of Tracking Station Location Uncertainty and Measurement Bias Error During Phases of the Apollo Mission. Goddard Space Flight Center, X-507-67-70, February, 1967.
3. Mitchell, Paul H.: Preliminary MSFN Error Analysis for AS-504A. MSC IN 67-FM-29, March 1, 1967.
4. Berry, Ronald L.: Minutes of the Second Meeting of the Midcourse Phase Mission Techniques Working Group. MSC Memorandum 67-FM54-441, December 28, 1967.